

SCHOOL OF CIVIL ENGINEERING



JOINT HIGHWAY RESEARCH PROJECT

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EVALUATION OF BENEFITS OF THE
INDIANAPOLIS INNERBELT SYSTEM

Charles Dulic



PURDUE UNIVERSITY
INDIANA STATE HIGHWAY COMMISSION

78-17

Final Report

EVALUATION OF BENEFITS OF THE INDIANAPOLIS INNERBELT SYSTEM

TO: Harold L. Michael, Director
Joint Highway Research Project

August 2, 1978

File: 3-5-9

FROM: Robert D. Miles, Research Engineer
Joint Highway Research Project

Project: C-36-64I

The attached Final Report titled "Evaluation of Benefits of the Indianapolis Innerbelt System" is presented in fulfillment of the objectives of the research. It has been authored by Mr. Charles Dulic, Graduate Instructor in Research on our staff, under the direction of Professor Robert D. Miles.

The publication reports the benefits of the Indianapolis Innerbelt Freeway System in terms of travel time savings, accident savings, and vehicle operating cost savings for the year November 20, 1976-November 19, 1977 inclusive. Included in this report are estimates of time savings, number of accidents eliminated and operating cost savings attributable to the development and construction of the Innerbelt Freeway System.

The Report is submitted for acceptance as fulfillment of the objectives of the Study.

Respectfully submitted,

Robert D. Miles/RDM

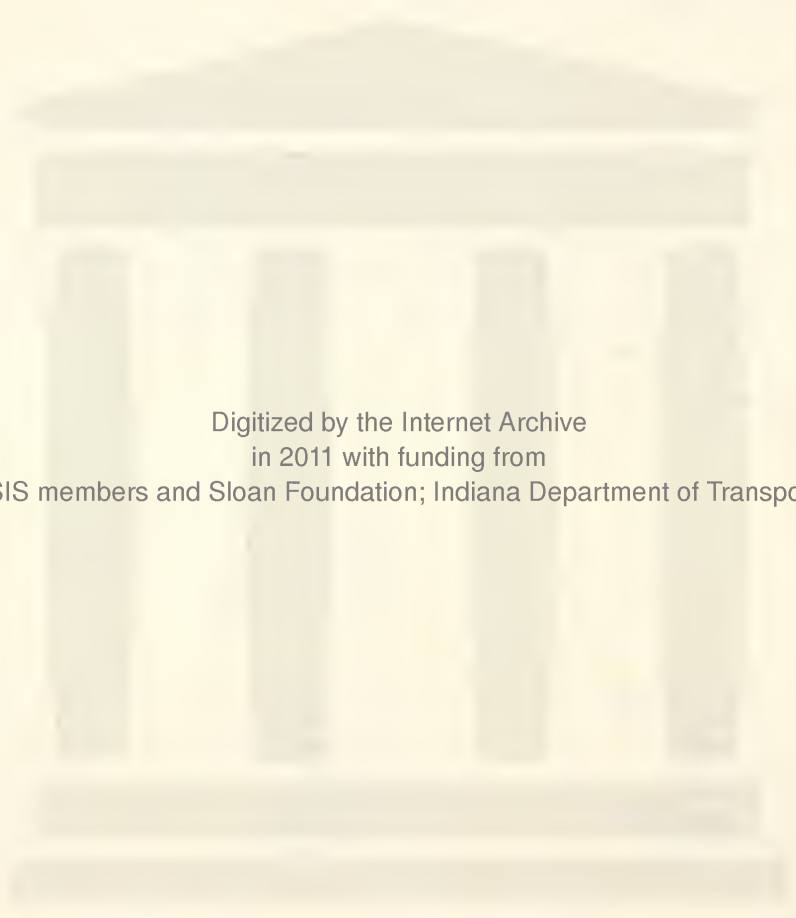
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Final Report

EVALUATION OF BENEFITS OF THE INDIANAPOLIS INNERBELT SYSTEM

by

Charles Dulic
Graduate Instructor in Research

Joint Highway Research Project

Project No.: C-36-64I

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Conducted by

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ABSTRACT

Dulic, Charles, M.S.C.E., Purdue University, August 1978. Evaluation of Benefits of the Indianapolis Innerbelt System. Major Professor: Robert D. Miles.

The purpose of this research effort was to identify and evaluate the benefits of travel time savings, accident savings, and vehicle operating cost savings attributable to the Indianapolis Innerbelt Freeway System. These road-user benefits were determined for a one year period, November 20, 1976 through November 19, 1977.

An underlying assumption used throughout this investigation was that, vehicles now utilizing the Innerbelt Freeway System would, in the absence of the Innerbelt System, have to utilize the surface arterial streets. This assumption was then modified to account for the induced traffic component of the Innerbelt Average Daily Traffic.

The benefits that accrued to the road-users due to the development and construction of the Innerbelt Freeway System were estimated as the additional travel time, accidents, and vehicle operating costs that would have occurred if the current Innerbelt Freeway travel was made on arterial streets.

Travel time, accident rate, and operating cost comparisons were made between Innerbelt routes I-65 and I-70, and corresponding arterial routes, U.S. 52 and U.S. 40.

It was found that the travel time savings attributable to the Innerbelt Freeway System amounted to approximately 9.7 million hours for the year studied.

It was estimated that due to the construction of the Innerbelt Freeway System, at least 2675 accidents were eliminated of which 16 would have been fatal, 854 would have involved personal injury, and 1805 would have involved property damage only.

The savings in operating costs attributable to the Innerbelt Freeway System was estimated at \$6,974,000 for the year November 20, 1976 through November 19, 1977.

CHAPTER I: INTRODUCTION

On October 15, 1976 the Indianapolis Innerbelt was opened to the public. This marked the advent of a total, continuous system of Interstate Freeways serving the Indianapolis-Marion County area. The previously segmented portions of Interstate 65 (I-65) and Interstate 70 (I-70) combined with Circum-urban Interstate 465 (I-465) could finally be considered a "system".

The Indianapolis Innerbelt, since its opening, has received some unfavorable publicity resulting from a few early accidents. Freeways, however, have produced sizeable benefits to many cities and have resulted in a reduction in the total number of accidents to the traffic affected. It was believed that the Indianapolis Innerbelt Freeway System also was resulting in a reduction of accidents, large travel time benefits and savings in vehicle operating costs. Data on these possible benefits, however, had not been systematically collected and analyzed.

It is obvious that the Innerbelt Freeway System provided roadways with design standards and operational characteristics superior to those of the surface arterial streets. A comparison of travel time, accidents and operating costs of travel on the System with those on arterial city streets would provide documentation of benefits to motorists from the System. With factual information on these benefits,

the value of the System to transportation in Indianapolis would be more accurately recognized and decisions relative to additional free-way type facilities could be more wisely made.

Purpose and Scope of Study

The purpose of this research was to identify and evaluate the impact of the following operational benefits that were directly attributable to the development of the Innerbelt Freeway System:

1. Travel Time Savings,
2. Accident Savings,
3. Vehicle Operating Cost Savings.

The study did not attempt to identify all the benefits or disbenefits of freeway operation, but merely those direct road-user benefits or disbenefits that comprise the basis of traditional user-benefit analyses. It was expected that the determination of benefits of the Innerbelt, as found in this investigation, would be conservative estimates of the actual benefits that would accrue to the road-users. Additional benefits of reduced air pollution, increased accessibility, and reduced need for additional surface streets, among others, were not investigated.

The evaluation of road-user benefits in the past has been involved with the transformation of benefits into dollars and cents. Since it was the aim of this study to identify and present freeway benefits in a clear and unequivocal manner, no attempt was made at the valuation of the saving of a human life or an hour of time. Only those benefits that lent themselves to measurement in monetary terms were expressed in dollars.

Among the numerous benefits of freeway operation that exist, this study was limited to an investigation of travel time savings, accident savings, and operating cost savings as they constitute the three most significant road-user benefits of freeway operation.

The investigation was also limited to a restricted study area.

Study Area

The study area was precisely that area within I-465 the circum-urban freeway around Indianapolis. The Innerbelt Freeway System was designated as those sections of I-65 and I-70 within I-465 exclusive of their interchanges with I-465 as shown in Figure 1. The "Innerbelt" was designated as those portions of I-65 and I-70 which lie immediately adjacent to the Central Business District (CBD) of Indianapolis as shown in Figure 2.

The elements of the study area's freeway and arterial routes are defined as follows:

Innerbelt Freeway System - the entire mileage of I-65 and I-70 within I-465, exclusive of their interchanges with I-465. The Innerbelt Freeway System is composed of the "Inner Belt" and the Radial Routes of I-65 and I-70 that connect the "Inner Belt" with the Outerloop, I-465.

Innerbelt - the "Inner Belt" is the freeway loop, immediately adjacent to the CBD, formed by the connection of Interstates 65 and 70.

Radial Routes - those portions of I-65 and I-70 which connect the "Inner Belt" with the Outerloop, I-465.

Arterial Routes - those surface streets within the study area with no control of access, no grade separated interchanges, and with signalized or stop control at intersections with cross streets.

The area boundaries chosen included all routes that had a significant effect on the Innerbelt Freeway System and its operation.

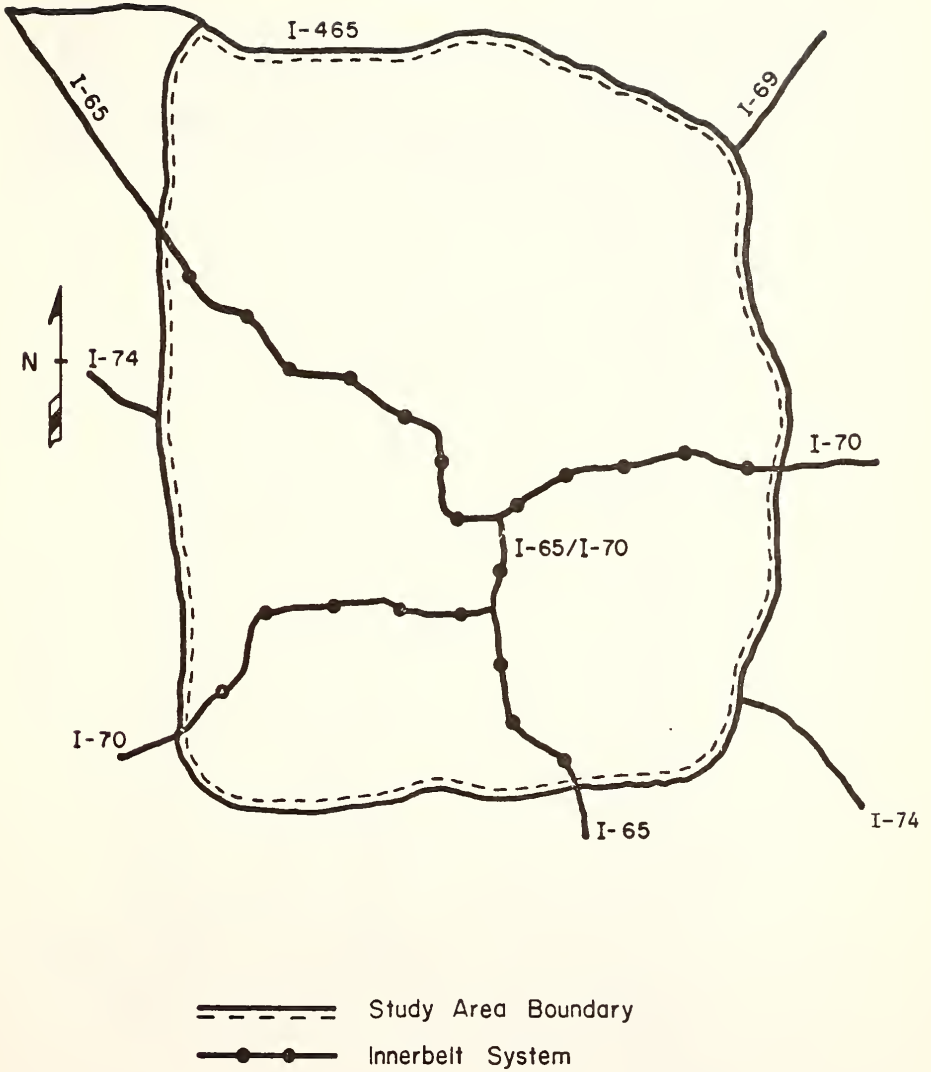


FIGURE 1 THE INNERBELT FREEWAY SYSTEM

I-65 I-70 INNERBELT

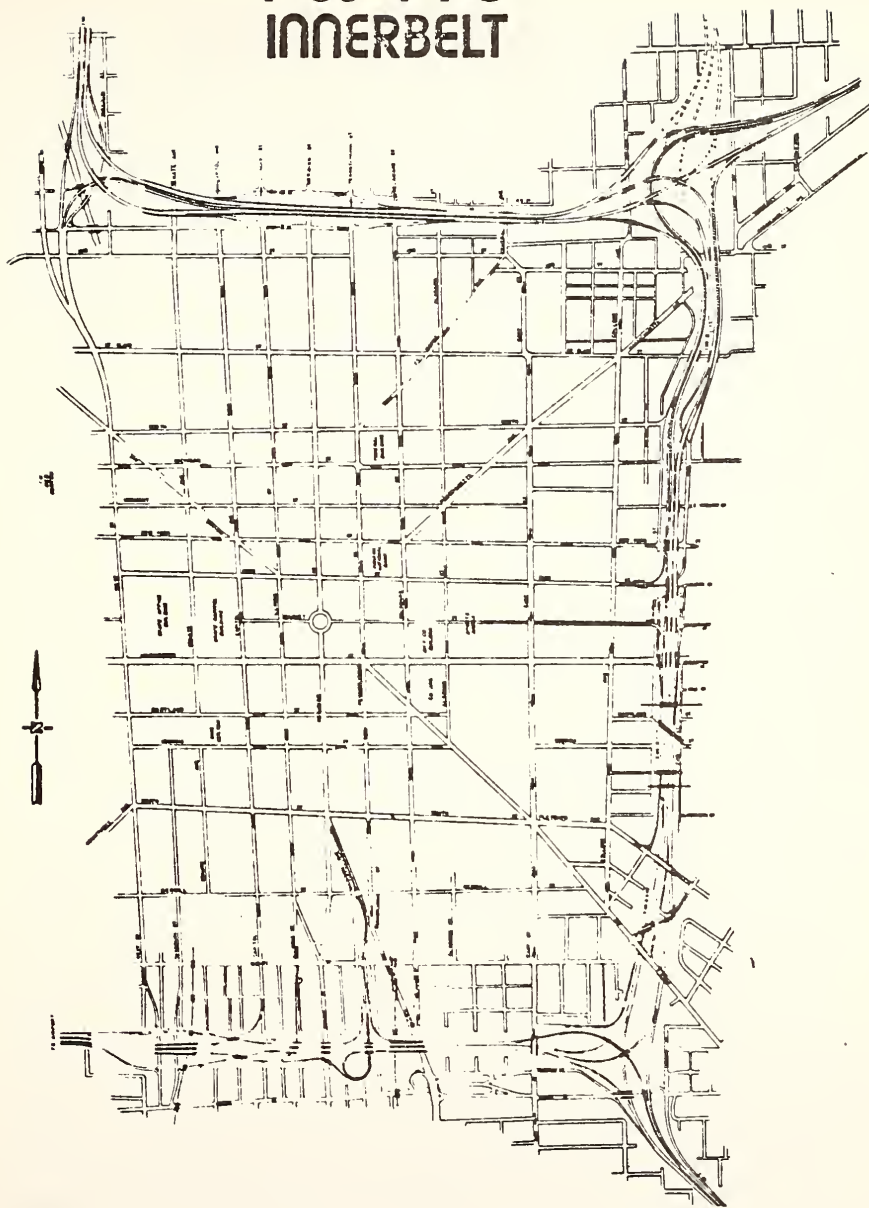


FIGURE 2 THE INNERBELT

Development of the Indianapolis Innerbelt

With the passage of the Federal-Aid Highway Act of 1956, the task of planning the Indianapolis Area Freeway System began. The Indianapolis Interstate System was to consist of three basic elements; the outerbelt, penetrating routes, and an innerbelt to connect the penetrating routes and serve as a collection and distribution system for CBD traffic. The system of radial routes (I-65, I-69, I-70, and I-74) were to facilitate the movement and interchange of local traffic from different sectors of the urban area (1). The innerbelt was necessary to interconnect the radial routes and to discharge traffic without breaking down the already overloaded circulation system in the urban area core (1).

Innerbelt Routes - The least costly alignment for the north leg of the Innerbelt was found to lie between 11th and 12th Streets (1). On the east, an alignment that fell between Davidson and Pine Streets was determined the most economical and the best location for crossing of the railroad complex east of the CBD (1). The west leg alignment proved to be somewhat difficult to locate. Due to highly concentrated industrial and commercial development between the CBD and the White River, along with the existence of a monument in Military Park that was in the National Register (1), a west leg of the Innerbelt was found to be impractical. Subsequently, the one-way pair of Senate and Capitol Streets was to serve the purpose of a west leg until a suitable alternative could be developed. To the south, the most practical alignment fell between Ray and Wilkins Streets (1).

Radial Routes - With the Innerbelt alignment given, the task of connecting the legs of the Innerbelt with four external control points on I-465 proceeded according to three basic criteria as cited by Ripple (1):

- "(1) routings were to be direct as practicable;
- (2) the junctions of the legs of the Innerbelt were to be as widely spaced as possible to avoid concentration of traffic at any one point, to reduce weaving movements, to provide sufficient length on the legs of the Innerbelt for weaving and distribution, and to minimize the number of lanes on the Innerbelt;
- (3) the radials should connect at the corners of the Innerbelt to allow terminating traffic a choice of two distributor legs of the Innerbelt, providing flexibility in traffic operation and avoiding concentrations of traffic on the distribution legs of the local circulation system" (1, pp. 421-422).

The final location of the Innerbelt with respect to the radial routes, I-65 and I-70, and the Outerbelt, I-465, is shown in Figure 3.

Previous Investigations

The Interstate System. The United States Department of Transportation (U.S.D.O.T.) performed a benefit study on the Interstate System (2) in the United States. The benefits of the Interstate System were found to be as impressive and as enormous as the actual undertaking of creating the 44,000 mile Interstate System.

Travel Time Savings. On intercity routes, the Interstate System was responsible for an average 10 percent reduction in travel times (2). Many Interstate corridors showed time savings of between 16 and 50 percent, with three corridors (I-91, North of New Haven, Conn.; I-95, Northeast from downtown Providence, R.I.; and I-15, South from Salt Lake City, Utah) experiencing time savings of 49 percent, 50 percent,

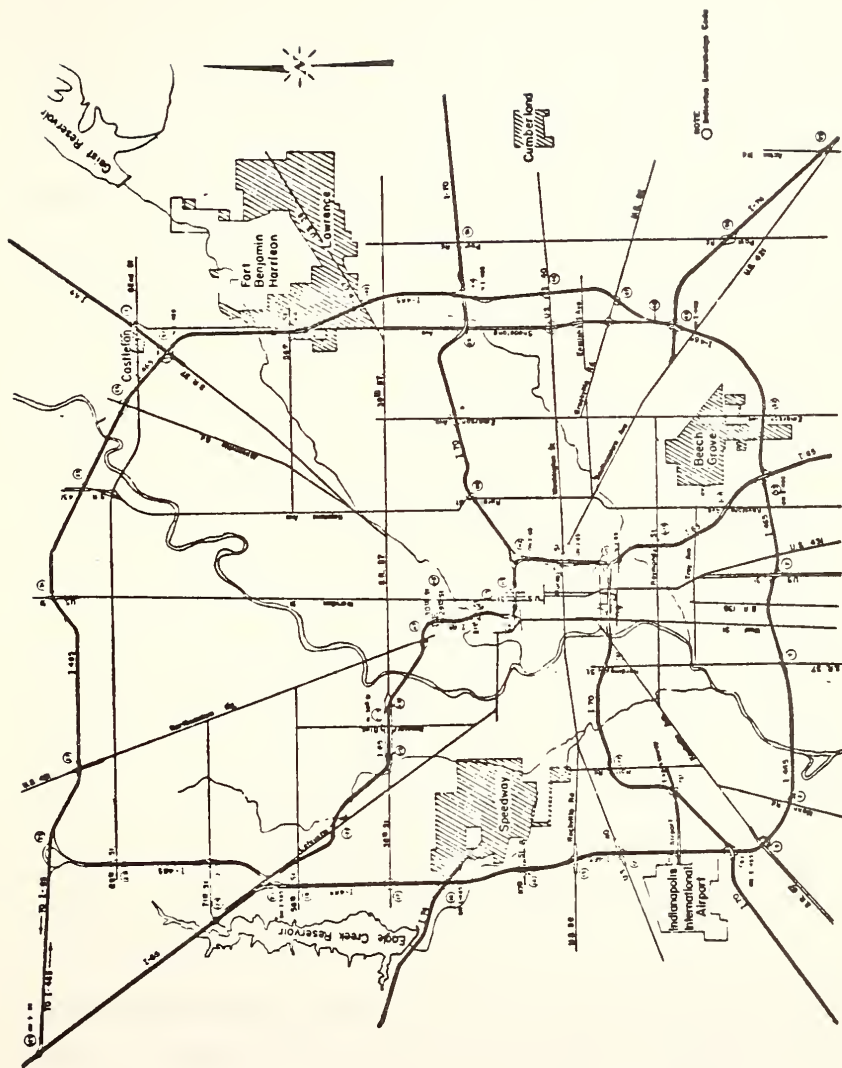


FIGURE 3 THE INNERBELT WITH RESPECT TO RADIAL ROUTES AND OUTERLOOP

and 60 percent respectively (2). Over the time period 1956-1979, the total estimated benefit of time savings due to the Interstate System, based on a value of time for trucks at \$5.56 per hour and a value of time for passenger vehicles at \$3.00 per hour, amounted to \$438 billion (2). The total cost of construction was estimated at \$70 billion (2).

Operating Cost Savings. The reduction in starts and stops and the elimination of barriers to constant speeds, provided by the high road-way design standards and superior operational characteristics of the Interstate System, resulted in a savings in vehicle operating costs amounting to \$45.8 billion for the period 1956-1979 (2).

Accident Reduction. Travel on Interstate highways has been shown to be significantly safer than travel on older highways which they supplement. The benefit of accident savings was estimated by the U.S.D.O.T. at \$15.8 billion for the period 1956-1979 (2). This estimate was the additional cost of accidents (fatalities, injuries, and property damage) that was forgone by the existence of the Interstate System. The reduction in accidents was found based on the results of the Interstate Accident Study (3), conducted on 7,000 miles of highway, which compared accident rates on highways before the existence of the Interstate and after sections of the Interstate System were completed.

The Milwaukee Freeway System. Batchelor, Sinha, and Chatterjee (4) performed a benefit-cost analysis of the Milwaukee Freeway System. Their findings indicated that the savings in travel time, accident savings, vehicle operating cost savings, and reduced capital expenditures for additional arterial streets due to the operation of

the freeway system, resulted in a benefit of \$37 million for the years 1962-1970 (4). The purpose of this study was to determine whether the benefits of the freeway system were greater than the cost of the city's lost tax base, since the freeway system took land off the tax rolls.

The accident cost savings were estimated at \$25,361,114 for 1962 through 1970, inclusive. The savings of travel time and operating costs were estimated at \$2,935,213 and \$6,642,252 respectively for 1962 through 1970. The freeway system also reduced the need for further arterial improvements by \$2.9 million for the nine year period. Similarly, the tax loss due to the construction of the freeway system within the city amounted to \$18,758,300 for 1962 through 1970. The benefits of the freeway, \$37,838,579, were more than twice the amount of the tax loss of \$18,758,330 for the years 1962 through 1970.

The Seattle Freeway System. Sawhill, Matteson, and Hall (5) examined the vehicle characteristics of fuel and travel time on urban arterials and freeways in the Seattle area. The total travel time savings for 1968 was estimated at \$30,737,000, about 12 percent of the construction cost. Of the \$30,737,000 travel time benefit, \$27,626,000 accrued to passenger vehicles while commercial vehicles received \$3,111,000 in benefits.

The total system fuel savings realized was estimated at \$366,000 for 1968. The major fuel benefits accrued to those vehicles that previously used arterial routes but were attracted to the freeway. The benefits of reduced travel time and reduced fuel consumption, attributable to

the Seattle Freeway System, totaled over \$31 million for the year 1968.

Method of Investigation

This investigation analyzed the impacts of three operational benefits of the Indianapolis Innerbelt Freeway System. The following road-user benefits were investigated; travel time savings, accident savings, and vehicle operating cost savings.

Determination of freeway benefits involved a comparison of freeway routes, I-65 and I-70, and their corresponding arterial routes, U.S. 52/U.S. 31 and U.S. 40. Throughout the investigation a basic assumption was used; vehicles now utilizing the Innerbelt Freeway System would, in the absence of the Innerbelt, have to utilize the surface arterial streets. Adjustments were made to account for induced traffic, assumed to be 20 percent of the total Innerbelt Average Daily Traffic (ADT). Benefits were then determined as the additional costs of travel time, accidents, and vehicle operating costs that were eliminated by the construction and operation of the Innerbelt Freeway System.

Benefits were determined for passenger vehicles only. Since commercial vehicles generally receive greater road-user benefits from freeway operation than do passenger vehicles, all benefits presented in this investigation are conservative estimates of the actual benefits that accrued to the road-user.

The time period for which benefits were computed was the year, November 20, 1976 through November 19, 1977, inclusive. This time

period provided the necessary one full year of accident data from which the benefit of reduced accidents was determined. Additional data presented in this study was also obtained during the study period November 20, 1976 through November 19, 1977, inclusive.

CHAPTER II: TRAVEL TIME SAVINGS

Typically, the greatest single user-benefit of Freeway operation is travel time savings. Consequently, it was felt the most significant potential benefit of the Innerbelt Freeway System would be its travel time savings. The concept of travel time savings as expressed by Winfrey (6) is stated as follows:

"Time, in terms of travel, is consumed-utilized in getting from place A to place B. When a trip is made in less travel time than before, no time is actually "saved" even though that is the popular concept. Any difference in total travel time for the two trips was used merely in different occupations of time, either before starting the trip, or after arriving at the destination" (6, p. 264).

People travel for various reasons. Seldom is travel a goal in itself. Travel is usually a means to a specific end or goal. Thus, time saved travelling allows road-users more time to pursue the goals that lie at their destination. This is the nature of people's desire to save time travelling, and hence the reason road-users consider travel time savings the most outstanding benefit of freeway travel.

Procedure and Data Collection

Travel time savings attributable to the Innerbelt Freeway System were determined by means of a comparison of Innerbelt Routes (I-65 and I-70) and corresponding parallel arterial routes (U.S. 52 and U.S. 40). The study routes used in the travel time comparison, as shown in Figure 4, are listed as follows:

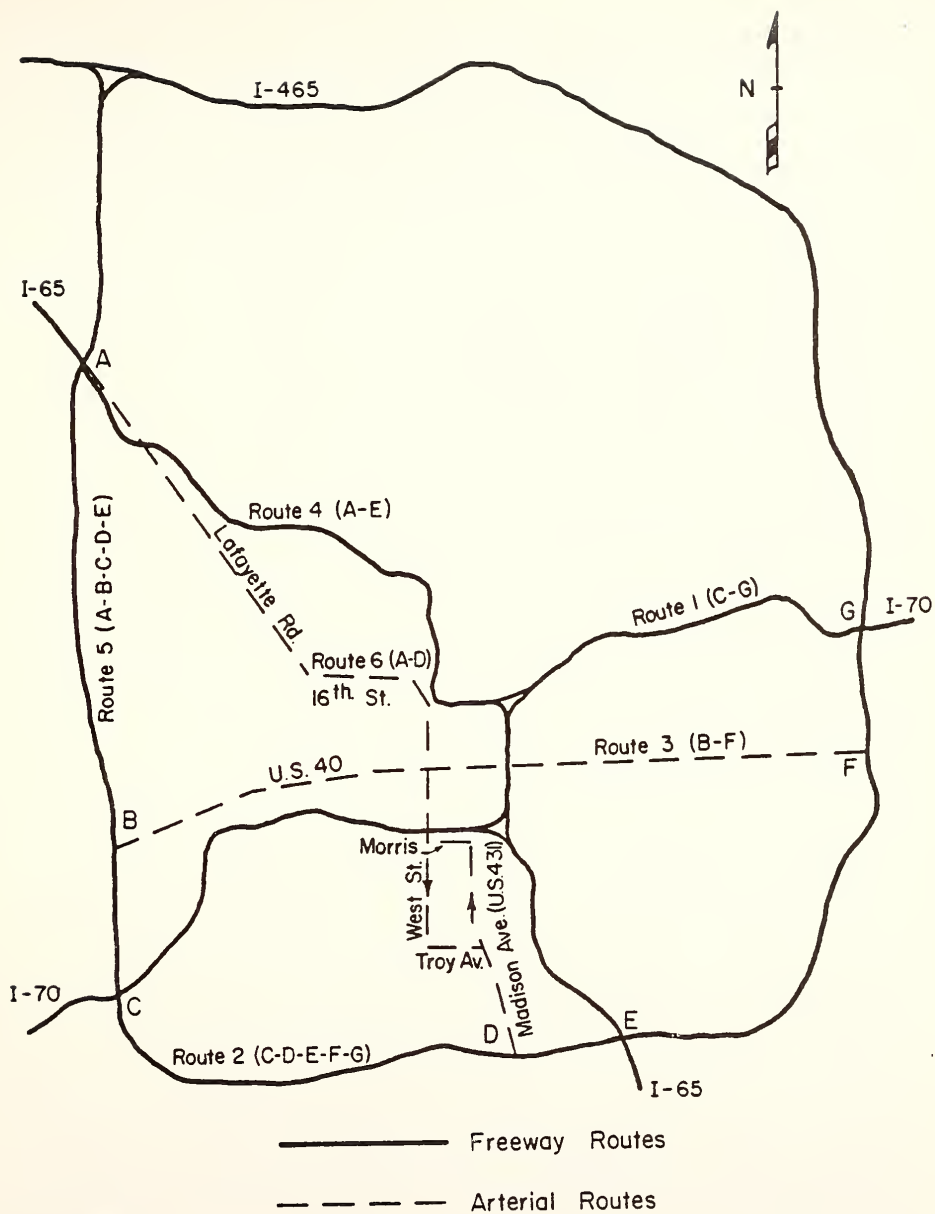


FIGURE 4 TRAVEL TIME ROUTES

Route 1 - A 16.6 mile section of I-70 between its east and west interchanges with I-465. Section C-G.

Route 2 - A 18.5 mile section of I-465 between its east and west interchanges with I-70 along the south. Section C-D-E-F-G.

Route 3 - A 12.5 mile section of U.S. 40 (Washington St.) between its east and west interchanges with I-465. Section B-F.

Route 4 - A 17.0 mile section of I-65 between its north and south interchanges with I-465. Section A-E.

Route 5 - A 19.7 mile section of I-465 between its north and south interchanges with I-65 along the west. Section A-B-C-D-E.

Route 6 - The parallel arterial routes to I-65; Section A-D.

Northbound - A 15.9 mile route composed of sections of Madison Ave., Morris St., West St., 16th St., and Lafayette Rd.

Southbound - A 15.3 mile route composed of sections of Lafayette Rd., 16th St., West St., Troy Ave., and Madison Ave.

On each of the six study routes, six test car runs were made:

1. in each direction of travel,
2. during both peak and off-peak periods.

All test car runs were made on typical weekdays i.e. Monday through Thursday. Test runs were made utilizing the Test Car Technique (11). The test vehicle operating criterion used was the Floating Car Technique (11) where the driver floats with the stream of traffic,

passing as many vehicles as pass the test car. Travel times were recorded for each test run and averaged for peak periods and off-peak periods, respectively. The average peak hour travel times and average off-peak hour travel times were then weighted according to the respective percentage of the ADT which occurred in that period. It was assumed that the peak period and off-peak period equalled 13 percent of the ADT and 87 percent of the ADT, respectively. Thus, a single ADT travel time was computed for each direction of each route as listed in Table 1. Sample calculations are shown in Appendix B.

Analysis of Data

Travel time comparisons were made between Innerbelt-Arterial routes and Innerbelt-Outerloop routes. In all comparisons, Innerbelt routes were designated as "Route Selected" and Arterial and Outerloop routes were designated as "Alternative Route". Comparisons were made and time savings determined as the difference in travel times between "Route Selected" and "Alternative Route", as shown in Table 2. These values represented the unit time savings per vehicle operating on Innerbelt routes. These unit values of time savings were then multiplied by the net volume of traffic that was diverted to the Innerbelt Freeway System (Total ADT-Induced Volume*). This provided an estimate of the total travel time savings attributable to the Innerbelt Freeway System as shown in Table 3.

Summary

As expected, the travel time savings attributable to the Innerbelt Freeway System were quite large. The greatest travel time

*For discussion of Induced Volume see pg. 27.

Table 1. Average Daily Traffic Travel Times

[East-West Routes]			
Route	Length (Miles)	Volume*(ADT)	ADT Travel Times (Min.)
1 - I-70 E	16.6	26,924	17.23
2 - I-465 E	18.5	26,317	18.61
3 - U.S. 40 E	12.5	11,630	31.88
1 - I-70 W	16.6	28,678	17.50
2 - I-465 W	18.5	25,897	18.71
3 - U.S. 40 W	12.5	11,404	32.08
[North-South Routes]			
Route	Length (Miles)	Volume (ADT)	ADT Travel Times (Min.)
4 - I-65 N	17.0	29,775	17.77
5 - I-465 N	19.7	28,773	19.86
6 - U.S. 52 N	15.9	8,827	38.07
4 - I-65 S	17.0	28,898	17.81
5 - I-465 S	19.7	28,587	19.77
6 - U.S. 52 S	15.3	8,827	37.71

*Weighted ADT for entire length of Section. See Appendix A for explanation of calculation method.

Table 2. Travel Time Savings Per Vehicle

Route Selected/Alternate Route		Travel Time Savings Per Vehicle (Min. Per Vehicle)
1 - I-70 E	3 - U.S. 40 E	14.65
1 - I-70 E	2 - I-465 E	1.38
1 - I-70 W	3 - U.S. 40 W	14.58
1 - I-70 W	2 - I-465 W	1.21
4 - I-65 N	6 - U.S. 52 N	20.30
4 - I-65 N	5 - I-465 N	2.09
4 - I-65 S	6 - U.S. 52 S	19.90
4 - I-65 S	5 - I-465 S	1.96

Table 3. Total Travel Time Savings for Innerbelt Freeway Routes

Innerbelt Route	Innerbelt Alternate Route	Innerbelt Average Volume (ADT)	Innerbelt Induced Volume* (ADT)	Total Diverted Volume (ADT)	Unit Travel Time Savings (Min. Per Vehicle)	Total Travel Time Savings (Hours Per Yr.)
I-70 E	U.S. 40 E	26,924	5,385	21,539	14.65	1,919,574
I-70 E	U.S. 40 W	28,678	5,736	22,942	14.58	2,034,841
					Total	3,954,415
I-65 S	U.S. 52 S	28,898	5,780	23,118	19.90	2,798,627
I-65 N	U.S. 52 N	29,775	5,955	23,820	20.30	2,941,572
					Total	5,740,199
I-70 E	I-465 E	26,924	5,385	21,539	1.38	180,820
I-70 W	I-465 W	28,678	5,736	22,942	1.21	168,872
					Total	349,692
I-65 S	I-465 S	28,898	5,780	23,118	1.96	275,644
I-65 N	I-465 N	29,775	5,955	23,820	2.09	302,851
					Total	578,495

*Assumed Induced Volume = 20% of ADT.

savings accrued to road users utilizing the Innerbelt Freeway System (Routes 1 and 4) instead of the arterial street system (Routes 3 and 6). This savings amounted to approximately 9.7 million hours of travel for the year studied, November 20, 1976-November 19, 1977. Of this 9.7 million hours of travel time saved, approximately 5.7 million hours were attributable to Interstate 65, route 4, and approximately 4 million hours were attributable to Interstate 70, route 1.

Comparatively, only a small time savings was realized by vehicles utilizing the Innerbelt Freeway System instead of the Outerloop I-465, routes 2 and 5. This savings amounted to approximately 927 thousand hours of travel for the year studied, November 20, 1976 to November 19, 1977. Again the I-65 corridor accounted for a greater percentage of the total savings than did Interstate 70. Of the 928 thousand hours saved, approximately 578 thousand hours were attributable to I-65 and approximately 350 thousand hours were attributable to I-70 for the year November 20, 1976 to November 19, 1977, inclusive.

Although only a small savings in time was realized by the Innerbelt Freeway System operation in comparison to the Outerloop, one should not be misled into thinking that the Innerbelt Freeway System was not needed. Although only a short amount of time was saved by the Innerbelt Freeway System compared to the Outerloop, an important condition is that the Innerbelt Freeway System serves many trips along its length which the Outerloop could not. Either could serve the trips through Indianapolis but for a city the size of Indianapolis these are a relatively small percentage of the total. Furthermore their use of the Outerloop would result in an earlier need for expanding the Outerloop to more lanes or in greater congestion during peak periods.

CHAPTER III: ACCIDENT SAVINGS

Accident savings are a potential user-benefit of the Innerbelt Freeway realized by high roadway design standards and superior operational characteristics. The objective of this portion of the investigation was to determine the benefits of improved safety provided to the road-users by the development of the Innerbelt Freeway System.

Procedure and Data Collection

Accident savings attributable to the Innerbelt Freeway System were determined by means of a comparison between accident rates on the Innerbelt Freeway System (I-65 and I-70) and the arterial street system in the study area. The accident savings were determined as the difference between the number of accidents that would have occurred "without" the Innerbelt Freeway System and the number of accidents "with" the System. Again, it was assumed that if the Innerbelt Freeway System were not constructed, the traffic now utilizing the System would have to utilize the arterial street system instead.

The comparison of arterial and freeway systems required the computation of accident rates on each of the two systems. These accident rates were computed according to the following expression (10):

$$R_s = \frac{A \times 10^8}{T \times V \times L}$$

where

R_s = section rate in accidents per hundred million vehicle miles travelled (Acc./HMVM).

A = number of accidents recorded in T days.

T = period for which accidents were counted (365 days).

V = average daily traffic (ADT) on a section.

L = length of section in miles.

The time period, T, for which accident data was obtained was one full year, November 20, 1976 through November 19, 1977 inclusive.

Freeway Accident Rate - In order to compute the accident rate on the Innerbelt Freeway System the following data was required; number of accidents, ADT on freeway sections, and length of freeway sections. The number and severity of Innerbelt and Radial Route accidents as shown in Table 4 were obtained from records maintained at the Indiana State Highway Commission.

Volumes, used in the accident rate computation, were obtained for segments of the Innerbelt and for the Radial Routes of I-65 and I-70 as obtained from the ISHC. These segment volumes were then weighted according to their individual lengths and a final weighted average ADT was determined for each section of the Innerbelt and the Radial Routes. These average ADT volumes for each section, section length, and Daily Vehicle Miles Travelled (ADT x Length) are shown in Table 5.

The accident rate for the Innerbelt and Radial portions of I-65 and I-70 were computed as follows:

Table 4. Freeway Accidents (11/20/76-11/19/77)

Fatal	Innerbelt		Property Damage	Fatal	Radial Routes	
	Injury				Injury	Property Damage
3	93		155	1	136	384
Total = 251					Total = 521	

Note: Reported Accidents Only
Source: Indiana State Highway Commission (ISHC).

Table 5. Freeway Volumes and Vehicle Miles Travelled (VMT)

<u>Innerbelt</u>			
Section	Volume (ADT)	Length (Miles)	VMT
I-65 N.B.	51,068	4.84	247,169
I-65 S.B.	49,771	4.84	240,892
I-70 W.B.	34,505	1.77	61,074
I-70 E.B.	29,907	1.77	52,935
Total Daily Innerbelt VMT =			602,070
<u>Radial Routes</u>			
Section	Volume (ADT)	Length (Miles)	VMT
I-65 N.B.	21,307	12.17	259,306
I-65 S.B.	20,597	12.17	250,665
I-70 W.B.	27,945	14.08	393,466
I-70 E.B.	26,549	14.08	373,810
Total Daily Radial Route VMT =			1,277,247

$$\text{Rate}_{\text{Innerbelt}} = \frac{251 \times 10^8}{365 \times 602070} = 114 \text{ Acc./HMVM}$$

$$\text{Rate}_{\text{Radial Routes}} = \frac{521 \times 10^8}{365 \times 1,277,247} = 112 \text{ Acc./ HMVM}$$

It should be noted that the accident rates for the Innerbelt and Radial Routes are essentially the same. It is not the case, as publicity has led many to believe, that the Innerbelt is more dangerous. The Innerbelt is experiencing more accidents than the Radial Routes on a per mile basis but that is due to the much higher volumes operating on the Innerbelt. On a per vehicle mile basis - a probable hazard measure relative to each vehicle operating on the facilities - there is no difference between the accident experience on the Innerbelt and on the Radial Routes of I-65 and I-70.

Arterial Accident Rate - The determination of a corresponding arterial accident rate was more complicated than determining the freeway rates due to the difficulty in stratifying accident reports into only arterial accidents. To circumvent this problem, the arterial accident rate to be used in the comparison was arrived at based on two separate accident rates. The first of these two rates was that of 38th Street in Marion County. The number of accidents, volumes, and vehicle miles travelled were obtained from the Indianapolis Department of Transportation and the rate calculated.

$$\text{Rate}_{38\text{th}} = \frac{1194 \times 10^8}{365 \times 398,644} = 821 \text{ Acc./HMVM}$$

The accident rate on 38th Street was found to be the highest accident rate of any arterial street in the study area according to Earl Sturgeon, Indianapolis Department of Transportation. Since this rate provided an upper bound, a lower bound was required to determine a representative arterial accident rate for the system of surface

arterials. The second arterial rate used, as obtained from the ISHC, was 478 Acc./HMVM. This rate was the average arterial accident rate for urban areas in Indiana. Based on these two arterial accident rates, it was assumed that the actual representative arterial accident rate would be: (1) larger than the statewide average of 478 Acc./HMVM due to the characteristics of a large urban area such as Indianapolis; (2) smaller than 821 Acc./HMVM since this figure represented the single highest arterial accident rate in the study area. Based on these observations, it was assumed that 600 Acc./HMVM reflected a representative arterial accident rate for the study area.

Estimated Reduction in Accidents

The accident savings were determined as the reduction in accidents that occurred in the study area due to the development of the Inner-belt Freeway System. The estimated reduction in accidents, or the additional number of accidents that would have occurred if the Inner-belt Freeway System, Innerbelt plus Radial Routes, was not built is expressed as follows (3):

$$O = T_F (R_A - R_F)$$

where

O = estimated reduction in occurrences (i.e. accidents).

T_F = total annual VMT on freeway that would have occurred on arterials in the absence of the freeway system.

R_A = arterial accident rate, Acc./HMVM.

R_F = freeway accident rate, Acc./HMVM.

In the above expression $T_F = \text{Annual VMT} - \text{Induced VMT}$. The induced traffic was assumed to be 20 percent of the ADT in this investigation. Although no exact value of induced traffic was available for the Innerbelt Freeway System a range of values was found from which the assumed 20 percent was derived. On newly opened highway facilities in Texas, a value of induced traffic was found by Holder (12) to be between 24-49 percent of the total freeway volume. Personnel of the Division of Planning, Department of Metropolitan Development in Indianapolis, reported they found as acceptable for planning purposes the values of 10-15 percent. From these two estimates of induced traffic, a value of near 20 percent was determined to be appropriate.

The estimated reduction in accidents as computed by $O = T_F(R_A - R_F)$ is shown in Table 6. The accidents that were eliminated by the operation of the Indianapolis Freeway System were then stratified by severity. Tamburri (7) developed a series for the percentage distribution of accidents by severity for several classifications of roads. The Percentage Distribution by Accident Severity, Table 7, was based on results from his national study. The percentages used from Tamburri were average values for 4 or more lane undivided roadways. These were applied to the arterial streets of this study as they were primarily of the 4 or more lane undivided type.

The distribution of eliminated accidents into number of fatal, injury, and property damage accidents as shown in Table 8, is the accident savings realized by the development and operation of the Indianapolis Innerbelt Freeway System.

Table 6. Estimated Reduction in Accidents

	Annual VMT	Induced VMT	T_F	R_A	R_F	$T_F (R_A - R_F)$
Innerbelt	219,755,550	43,951,110	175,804,440	600.0	114	854
Radial Routes	466,195,155	93,239,031	372,956,124	600.0	112	1820

Note: $T_F (R_A - R_F)$ = Estimated Reduction in Accidents.

Table 7. Percentage Distribution by Accident Severity

Facility	Fatal	Severity Injury	Property Damage
4 or More Lane Undivided	.006	.319	.675

Source: Reference 7.

Table 8. Distribution of Eliminated Accidents by Severity

Facility	Fatal	Severity	
		Injury	Property Damage
Innerbelt	5	273	576
Radial Routes	11	581	1229
Innerbelt System	16	854	1805
		GRAND TOTAL	2675 accidents

Summary

For the year November 20, 1976–November 19, 1977, the Innerbelt Freeway System eliminated at least 2675 accidents. Of these 2675 eliminated accidents, 16 would have been fatal, 854 would have involved personal injury, and 1805 would have involved property damage only.

More specifically, the Inner Belt portion of the total System was responsible for eliminating 854 of the total 2675 accidents, of which 5 would have been fatal, 273 would have involved personal injury, and 576 would have involved property damage only. The Radial portions of I-65 and I-70 were found responsible for eliminating 1820 accidents, of which 11 would have been fatal, 581 would have involved personal injury, and 1229 would have involved property damage only.

CHAPTER IV: OPERATING COST SAVINGS

There are certain costs associated with operating a vehicle on freeways and arterial streets. Those costs of operating a motor vehicle are borne by the owners of the motor vehicles, the road-users. Factors (6) that affect the operating cost are listed as follows:

A) The Highway

1. Distance
2. Geometric Design
3. Surface
4. Traffic volume, composition, traffic controls, and speed changes

B) The Vehicle

1. Road weight, and weight-horsepower ratio
2. Engine Design
3. Tire size and pressure
4. Vehicle dimensions and dynamic characteristics
5. Type of fuel

C) The Operator

1. Speed changes (rates of acceleration and deceleration)
2. Cruising Speed
3. Character of use, trip length
4. Care of vehicle

D) The Weather

1. Air temperature, air pressure, and air humidity
2. Wind direction and velocity
3. Rain, snow, and ice conditions on roadway
4. Altitude and topography

This study investigated the savings in operating costs attributable to the Innerbelt Freeway System. Since the operating cost savings were determined for freeway versus arterial street travel, only those factors dependent on the highway were used in the investigation. It was assumed all other factors of the vehicle, the operator, and the weather would remain the same for cost of operation on both freeways and arterial streets.

Procedure

Operating cost savings attributable to the Innerbelt Freeway System were determined by means of a comparison of Innerbelt Routes (I-65 and I-70) and corresponding parallel arterial routes (U.S. 52 and U.S. 40). The study routes used in the comparison were the same as those used in computing travel time savings.

Operating costs, comprised of running costs, speed change costs, added cost due to stopping, and costs due to idling were determined for Innerbelt Routes and Arterial Routes. The final estimate of operating cost savings was the difference in the operating costs for Freeway routes and Arterial routes multiplied by the volume of traffic on the Innerbelt Routes, ADT minus Induced Traffic. Again the induced traffic component of the Freeway volumes was assumed to be 20 percent of the ADT occurring on Innerbelt routes.

The following components of operating cost were determined on a per vehicle basis for both Innerbelt routes I-65 and I-70, and Arterial routes U.S. 52 and U.S. 40:

1. Running Cost,
2. Speed Change Cost,
3. Stopping Cost,
4. Idling Cost.

Running Costs and Speed Change Costs

The factors affecting the running cost component and speed change component of the total operating cost were average running speed, volume-to-capacity ratio (V/C), mileage of various grades, and mileage of various degrees of curvature. For freeway travel with operating speeds ≥ 55 mph and with two lanes per direction, a V/C ratio of 0.50 was found appropriate (8). For arterial street operation with an average overall speed of ≥ 20 mph, a V/C ratio of 0.80 was found appropriate (8). For the routes used in the comparison, U.S. 40 and U.S. 52, and I-70 and I-65, the average running speeds and overall travel speeds are shown in Table 9. These speeds were determined based on the Test Car Technique results. Speeds were computed by simple distance divided by time relationships for each study route.

Given average running speeds and V/C ratios for freeway and arterial routes, the running costs and speed change costs may be found from Figures 5 and 6. Curve and grade data for freeway and arterial routes, mileage of each curve and grade section as a percentage of the total roadway length, and the running cost associated with each degree of curve and percent grade are shown in Table 10.

Table 9. Test Car Technique Freeway and Arterial Speeds (MPH)

Route	Length (miles)	Average Running Speed	Overall Travel Speed
I-65	17.0	57.3	57.3
I-70	16.6	57.3	57.3
		Avg.	57.3
U.S. 52	15.6	28.8	24.7
U.S. 40	12.5	27.2	24.3
		Avg.	24.5

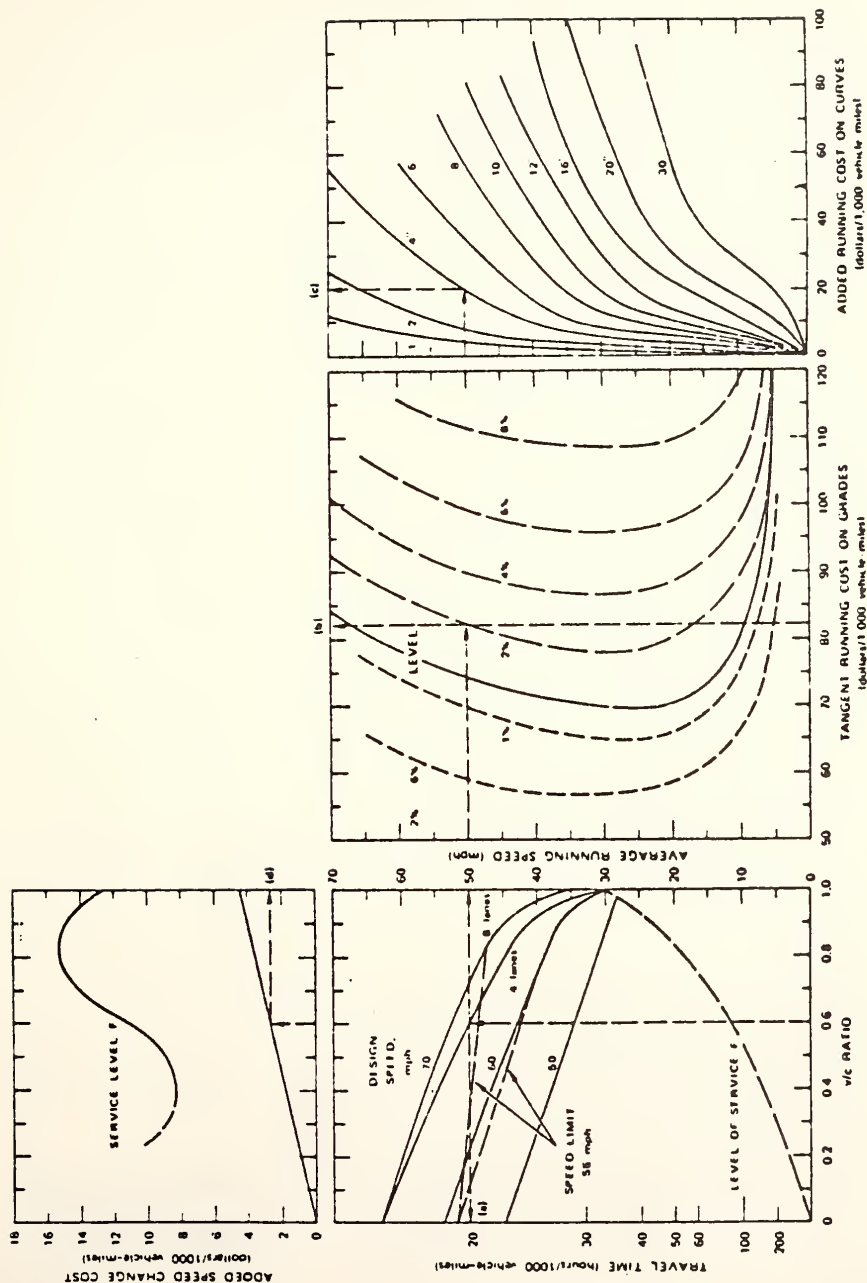


Figure 5. Running and Speed Change Costs on Freeways

Source: Reference (9)

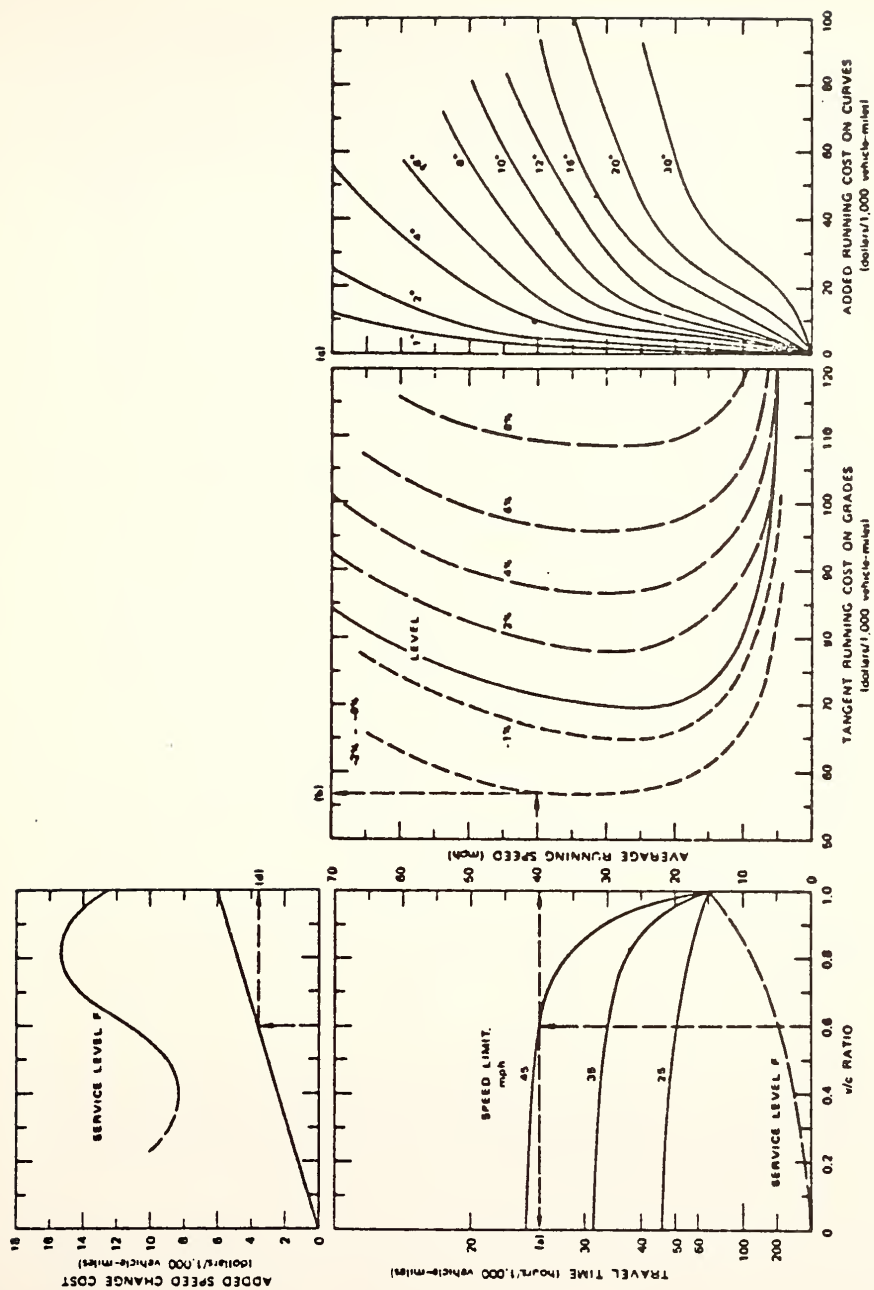


Figure 6. Running and Speed Change Costs on Arterials

Source: Reference (9)

Table 10. Costs Due to Curves and Grades

Freeways (I-65 and I-70)		
Curves (Degree)	Percent of Total Length	Running Cost(\$/1000 veh-mi)
Tangent	63.1	0
1°	10.0	4
2°	17.5	10
3°	2.9	19
4°	3.3	30
5°	0.0	38
6°	1.2	50
7°	0.5	60
8°	1.0	80
9°	0.5	95
Grades (Percent)	Percent of Total Length	Running Cost(\$/1000 veh-mi)
-4	0.1	
-3	6.1	60
-2	9.9	
-1	6.5	72
Level	55.2	77
+1	7.6	80
+2	9.3	84
+3	5.3	88
Arterials*(U.S. 40 and U.S. 52)		
Curves (Degree)	Percent of Total Length	Running Cost(\$/100 veh-mi)
Tangent	100.0	0
Grades (Percent)	Percent of Total Length	Running Cost(\$1/1000 veh-mi)
Level	100.0	70

*Arterial curve and grade data were not available. As an assumption that these roadways had no curves or grades would result in a conservative estimate of the operating costs, this assumption was made.

Using Table 10 the running costs for freeway and arterial routes were determined as follows:

$$\text{Running Cost}_{\text{Curves}} = \Sigma(\text{running cost on curve, \$/1000 veh-miles}) \\ \times (\text{percent of total length})$$

$$\text{Running Cost}_{\text{Grades}} = \Sigma(\text{running cost on grade, \$/1000 veh-miles}) \\ \times (\text{percent of total length})$$

Sample cost calculations are shown in Appendix C. The running costs, in dollars per vehicle making a trip on each arterial and freeway route, appear as shown in Table 11. The costs shown in Table 11 include the costs due to running a vehicle on grades and curves and the costs due to speed changes, but do not include the costs due to stopping or idling. The latter two costs are determined in the following sections.

It should be noted that the running cost component of total operating cost is greater for freeway routes than arterials. This, of course, results from the higher running speeds on the freeway system.

Costs Due to Stopping at Intersections

Stopping costs include the costs of bringing a vehicle to a stop from a given speed and accelerating back up to that given speed. They do not include the costs incurred while the vehicle is stopped, such as idling cost. Only arterial streets will incur a stopping cost since freeway travel was assumed to be uninterrupted by stops.

For the arterial routes used in this investigation, pertinent data used in determining the costs of stopping for vehicles travelling on U.S. 40 and U.S. 52 are shown in Table 12. The actual range of green-to-cycle time ratios was between 0.5 for intersections of

Table 11. Running Costs for Freeway and Arterial Routes (\$/vehicle)

Cost Item	Freeway		Arterial	
	I-65	I-70	U.S. 52	U.S. 40
Curves	0.10	0.10	0.00	0.00
Grades	1.28	1.25	1.09	0.88
Speed Changes	0.03	0.03	0.08	0.06
Total	1.41	1.38	1.17	.94

Table 12. Arterial Street Data

Item	U.S. 40	U.S. 52
Volume-to-Capacity Ratio, V/C	0.8	0.8
Approach Speed	28 mph	28 mph
Green-to-Cycle Time Ratio, γ	0.6	0.6
Number of Signals	51	44

equally important streets and 0.7 for intersections of U.S. 40 and U.S. 52 with only minor streets. Consequently, a value of $\gamma = 0.6$ was assumed to be a satisfactory value for the arterials used in this investigation.

Given the V/C ratio, γ , and approach speed, the cost due to stopping, in dollars per 1000 vehicles (per signal), was found from Figure 7. The stopping cost for a trip utilizing U.S. 40 and U.S. 52, in dollars per vehicle, was found to be \$0.54 per vehicle and \$0.46 per vehicle for U.S. 40 and U.S. 52, respectively.

Idling Costs

Idling costs associated with vehicles stopped at intersections were investigated for U.S. 40 and U.S. 52, the arterial routes in the study area.

Idling costs were found to be dependent on V/C ratio, capacity of approach, and the green-to-cycle time ratio, γ . The capacity of approach was estimated for a typical intersection along each arterial route, U.S. 40 and U.S. 52, to be $C = \gamma \cdot S$, where γ = green-to-cycle time ratio and S = the saturation flow. Saturation flow, the approach volume in vehicles per hour of green when the load factor is 1.0, was determined to be 1700 vehicles per hour times the number of approach lanes (9). Given values of γ , V/C, approach speed, and capacity the idling cost in dollars per 1000 vehicles per signal may be found from Figure 8. Idling costs in dollars per vehicle are shown in Table 13. These idling costs appear insignificant on a per vehicle basis but nevertheless are another cost of travelling on arterials that is eliminated by freeway travel.

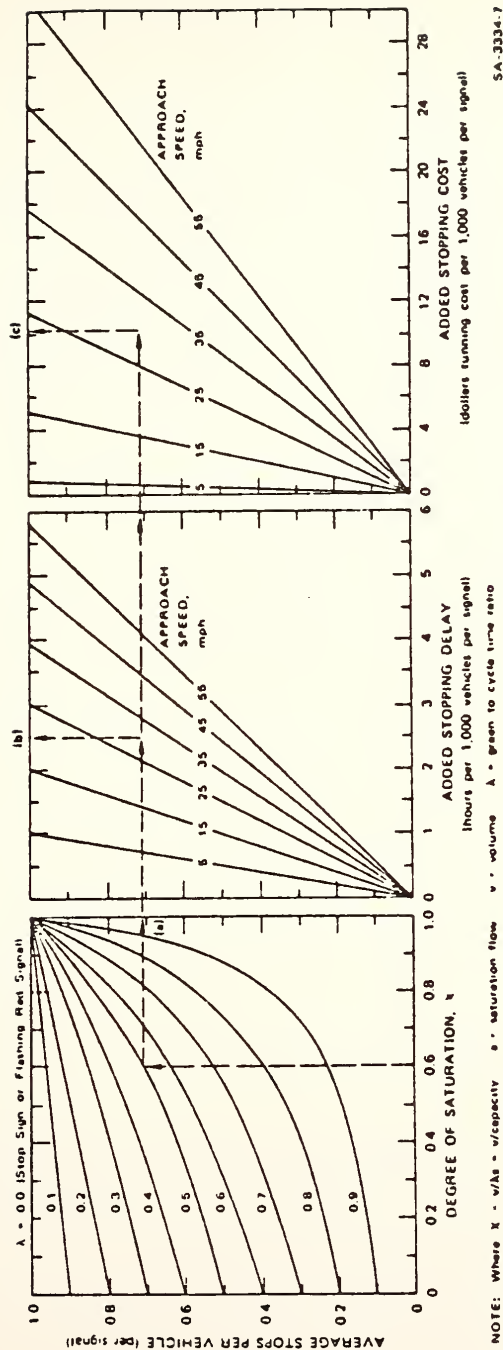
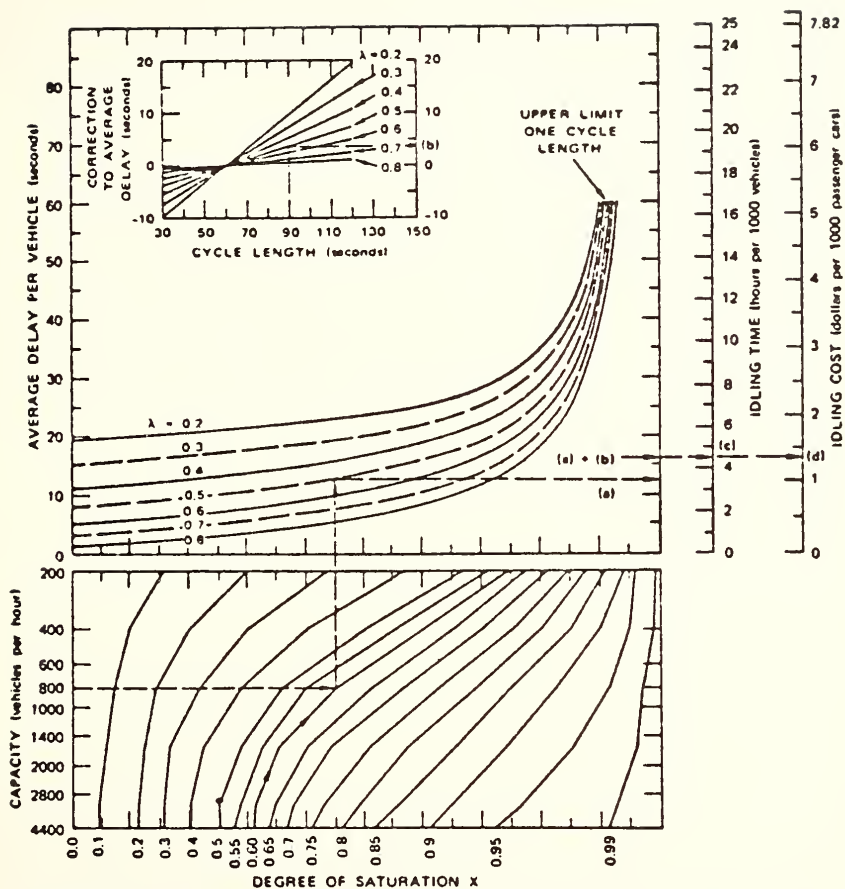


Figure 7. Costs Due to Stopping at Intersections

Source: Reference (9)



NOTE: Where: $X = v/\lambda s = v/\text{capacity}$ s = saturation flow v = demand volume λ = green to cycle time ratio

Figure 8. Costs Due to Idling at Intersections

Source: Reference (9)

Table 13. Idling Costs (\$/Vehicle)

	U.S. 40	U.S. 52
V/C	0.8	0.8
γ	0.6	0.6
Capacity*	2040	2040
Approach Speed	28 mph	28 mph
Average Delay per Veh.	12 sec.	12 sec.
Number of Signals	51	44
Idling Cost per Route (\$/vehicle)	0.051	0.044

*Capacity = $\gamma \cdot S = (.6) \times (1700 \times 2 \text{ lanes}) = 2040 \text{ vehicles per hour.}$

Table 14. Operating Cost Comparison (\$/Vehicle)

Route	Running and Speed Change Cost	Stopping Cost	Idling Cost	Operating Cost
U.S. 52	1.170	0.460	0.044	1.674
I-65	1.410	0	0	1.410
			Operating Cost Savings =	0.264
U.S. 40	0.940	0.540	0.051	1.531
I-70	1.380	0	0	1.380
			Operating Cost Savings =	0.151

Table 15. Operating Cost Savings for Innerbelt Freeway Routes

Innerbelt Route	Arterial Route	Innerbelt Route Average Volume (ADT)	Innerbelt Induced Volume (20%)	Total Diverted Volume (ADT)	Operating Cost Savings (\$/veh)	Total Operating Cost Savings (\$/Year)
I-70 E	U.S. 40 E	26,924	5,385	21,539	0.151	1,187,000
I-70 W	U.S. 40 W	28,678	5,736	22,942	0.151	1,264,000
					Total	2,451,000
I-65 S	U.S. 52 S	28,898	5,780	23,118	0.264	2,228,000
I-65 N	U.S. 52 N	29,775	5,955	23,820	0.264	2,295,000
					Total	4,523,000

Operating Costs

The total operating cost savings were estimated as the difference in operating costs per vehicle, for freeway routes and arterial routes, multiplied by the volume of traffic on the freeway routes (ADT - Induced). The operating costs in dollars per vehicle, for each arterial and freeway route are shown in Table 14. The difference in operating costs for comparable freeway and arterial routes is also shown in Table 14. The final estimate of the operating cost savings attributable to Innerbelt Routes I-65 and I-70 are shown in Table 15. These yearly savings of \$2,451,570 and \$4,522,945 for I-70 and I-65 respectively, represent the additional costs that would have occurred if the current I-70 and I-65 volumes were to operate on arterial streets.

Summary

The savings in operating costs attributable to the Innerbelt Freeway System was estimated at \$6,974,000 for the year November 20, 1976 to November 19, 1977. This figure of cost savings represents an estimate of the savings in running costs, speed change costs, costs due to stopping at intersections, and costs due to idling at intersections provided by the Indianapolis Innerbelt Freeway System. Of this \$6,974,000, \$2,451,000 were attributable to Interstate 70 between its interchanges with Interstate 465. Approximately \$4,523,000 in operating cost savings were attributed to Interstate 65 between its interchanges with Interstate 465.

CHAPTER V: CONCLUSIONS

This study has evaluated the road-user benefits of the Indianapolis Innerbelt Freeway System for the year November 20, 1976 through November 19, 1977 inclusive. Due to high roadway design standards and superior operational characteristics of the Innerbelt Freeway System, certain benefits are realized by the road users. Among the most outstanding road-user benefits are the travel time savings, accident savings, and operating cost savings. The objective of this investigation was to determine and evaluate the road-user benefits of reduced travel time, reduced accidents, and reduced operating costs that were attributable to the development and construction of the Innerbelt Freeway System. On the basis of findings during the investigation the following conclusions are made:

1. Large travel time savings resulted to road users from use of the Innerbelt Freeway System compared to what it would have been if they had to use the arterial street system. This time savings amounted to approximately 9.7 million hours for the year November 20, 1976-November 19, 1977.
2. Only a small time savings was realized by vehicles utilizing the Innerbelt Freeway System instead of the Outerloop (I-465) for through trips. The major value of the Innerbelt Freeway System, however, relative to the Outerloop is that the Innerbelt Freeway System serves many

motorists with origins or destinations along its routes which the Outerloop could not serve.

3. The accident rate, for all types of accidents combined, was found to be almost five times greater on arterial streets than on the Innerbelt Freeway System. However, at the same time, the Innerbelt Freeway System carried more than twice the ADT of the arterial routes studied.
4. An important finding of the research is that the accident rate on the Innerbelt (114 Acc/HMVM) was essentially the same as the accident rate on the Radial Portions of I-65 and I-70 (112 Acc/HMVM). It is concluded that the Innerbelt is no more hazardous than the Radial Routes connecting the Innerbelt to the Outerloop (I-465).
5. For the year studied the Innerbelt Freeway System eliminated at least 2675 accidents. Of these 2675 accidents that would have occurred in the absence of the System, 16 would have been fatal, 854 would have involved personal injury, and 1805 would have involved property damage only.
6. The running cost component of total operating cost was found to be higher for freeway routes than for arterial routes. This was due to the difference in running speeds for the two systems. The higher running cost on freeways, however, was more than offset by the additional costs of stopping and idling which occurred on the arterial routes but not exist on the freeway system. Due to absence of

starts and stops and other barriers to constant speeds, the Innerbelt Freeway System was responsible for approximately \$6.9 million in reduced operating costs for the year studied.

7. This study evaluated only travel time savings, accident savings, and vehicle operating cost savings. Other benefits and disbenefits resulted from the Innerbelt Freeway System and would be appropriate subjects for evaluation in further research.
8. The total annual benefits to motorists for the period November 20, 1976 through November 19, 1977 of the Indianapolis Innerbelt Freeway System was found to be 9.7 million hours in time saved, 2675 less accidents, and \$6.9 million in reduced operating costs.

CHAPTER VI: RECOMMENDATIONS FOR FURTHER RESEARCH

Through the course of this research, additional areas were identified that could be further studied to more completely evaluate the benefits of urban freeway systems. Some of these of greatest interest would be:

1. A study of the impact of the Innerbelt Freeway System on the economic growth of the Central Business District in Indianapolis. This research should evaluate the beneficial effect of increased accessibility, provided by an urban freeway, on the economic viability of the downtown area.
2. A detailed study of the impact of the Innerbelt Freeway on the air and noise pollution in the urban area. This research should compare the effects of acceleration noise, for freeway and arterial travel, on the air and noise pollution produced in the urban area.

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APPENDICES

APPENDIX A

Sample Volume Calculations

Estimated Average Freeway Volumes were determined by a weighting procedure. For each route, the total length was subdivided into segments with known ADT volumes. These volumes were then multiplied by the length of the segment for which that volume was valid. The final average estimated ADT volume for each freeway route was calculated by:

$$\text{Avg. ADT Volume} = \frac{(V_1)l_1 + (V_2)l_2 + \dots + (V_n)l_n}{L}$$

where V_i = ADT volume on segment i

l_i = length of segment i in miles

L = total length of freeway route, miles

<u>Example:</u>	<u>V_i (ADT)</u>	<u>l_i (Miles)</u>
I-70 W.B.	30607	.57
	28010	2.29
	34434	2.11
	38655	2.04
	34353	1.19
	34332	.18
	34332	.24
	29980	.91
	34711	1.34
	25745	2.07
	18468	1.88
	14521	1.78
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	476054.8	16.6

$$\therefore \text{Avg. Vol. I-70 W.B.} = \frac{476054.8}{16.6} = 28678 \text{ ADT}$$

APPENDIX B

Table B-1. Peak Period and Off-Peak Period Travel Times [Minutes]

Route	Peak Hr. T.T.	Off-Peak T.T.	ADT T.T.
U.S. 52 N	44.10	37.20	38.07
U.S. 52 S	45.10	36.65	37.71
I-65 N	18.22	17.71	17.77
I-65 S	18.19	17.75	17.81
I-465 N	20.24	19.81	19.86
I-465 S	19.94	19.75	19.77
U.S. 40 E	34.10	31.56	31.88
U.S. 40 W	35.13	31.64	32.08
I-70 E	17.83	17.15	17.23
I-70 W	17.96	17.44	17.50
I-465 E	18.98	18.56	18.61
I-465 W	18.92	18.69	18.71

Note: Peak Period = 13% ADT, Off-Peak Period = 87% ADT

Sample Calculation:

$$\text{ADT T.T.} = (\text{Peak Hr. T.T.}) \times (\text{Peak Hr. \%}) + (\text{Off-Peak Hr. T.T.}) \times (\text{Off-Peak Hr. \%})$$

I-65 N.B.

$$\text{ADT T.T.} = (18.22 \times .13) + (17.71 \times .87) = 17.77 \text{ minutes}$$

APPENDIX C

Sample Operating Cost Calculations

Running Costs (From Figure 5)

$$\text{Running Cost on Grades} = \Sigma[(\text{Running Cost on Grade, \$/1000 veh-mi.}) \\ \times (\% \text{ of Total Length})]$$

$$\begin{aligned} \text{I-65 Running Cost on Grades} = & (77 \times .565) + (80 \times .073) + (84 \times \\ & .090) + (88 \times .051) + (72 \times .063) + \\ & (60 \times .158) \end{aligned}$$

$$\text{I-65 Running Cost on Grades} = \$75 \text{ per 1000 vehicle miles.}$$

$$\begin{aligned} \text{Cost Per Vehicle} = & (\$75 \text{ per 1000 vehicle miles}) \times (17 \text{ miles}) \\ = & \$1.28 \text{ per vehicle.} \end{aligned}$$

Stopping Costs (From Figure 7)

$$\text{Stopping Costs on U.S. 40} = \$10.50 \text{ per 1000 vehicles (per signal)}$$

$$\begin{aligned} \text{Cost Per Vehicle} = & (\$10.50 \text{ per 1000 vehicles per signal}) \times (51 \\ & \text{signals}) = \$0.54 \text{ per vehicle} \end{aligned}$$

Idling Costs (From Figure 8)

$$\text{Idling Costs on U.S. 40} = \$1.00 \text{ per 1000 vehicles (per signal)}$$

$$\begin{aligned} \text{Cost Per Vehicle} = & (\$1.00 \text{ per vehicle per signal}) \times (51 \text{ signals}) \\ = & \$0.051 \text{ per vehicle} \end{aligned}$$

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